Royal Netherlands
Meteorological Institute
Ministry of Infrastructure and the Environment

Validation of the DOAS fitted ozone temperature and improvements for the operational method

Albert Oude Nijhuis, Maarten Sneep, Johan de Haan, Pepijn Veefkind*

For monitoring the ozone layer, multi-year trends in ozone need to be established with very high accuracy. Although it is well known that the ozone absorption cross sections are temperature dependent, most of the remote sensing algorithms disregard this effect. As a consequence, a temperature trend may cause a false ozone trend. Satellite retrievals using spectrometers can derive the ozone temperature from the spectra itself and provide total ozone values that are potentially independent from the temperature.

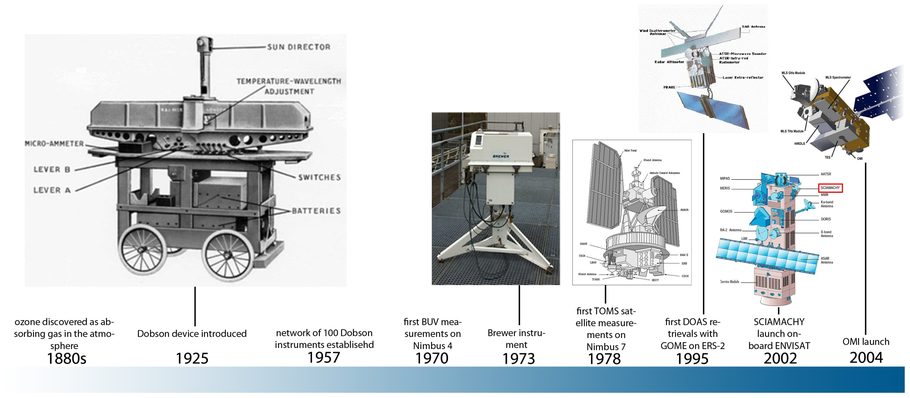


Figure 1: Illustration of the progress in ozone column observations.

History of ozone column observations

See Fig. 1 for an illustration of the progress in observations of the vertical column density of ozone. G. Dobson started the measurements. From the ratio of the radiation at different wavelengths he determined the thickness of the ozone layer. A. Brewer developed a similar instrument, fully automated but with a different wavelength combination. Long-term UV observations from space started in 1970 on board the US research satellite Nimubs 4. The first TOMS instrument was launched on Nimbus 7 in 1979, yet also with a different wavelength combination. A new type of observations became available with the launch of GOME (1995). By applying the DOAS method on the high spectral resolution data, it became possible to analyze the atmospheric absorption of a large variety of weak atmospheric absorbers such as ozone in the Huggins band. Contrary to the previous methods is that the DOAS method allows fitting of the ozone temperature from the spectra itself. After GOME (1995), the DOAS method is applied to several other satellite instruments, such as SCIAMACHY (2002), OMI (2004) and GOME-2 (2006).

OMI DOAS (OMDOAO3)

The key concept of the DOAS method is to fit the ozone absorption cross sections, see Fig. 2, to the measured atmospheric spectrum. The fit is performed with Eq. 1:

$$\frac{I(\lambda)}{F(\lambda)} = P(\lambda)\exp\left[-N_s\sigma_{O3}(\lambda, T_{\text{eff}})\right] \quad , (1)$$

where I is the earth radiance, F the solar irradiance, P a low-order polynomial, N_S ozone slant column density, $\sigma_{O3}(\lambda,T_{\text{eff}})$ ozone absorption cross section, λ the wavelength and T_{eff} the effective ozone temperature.

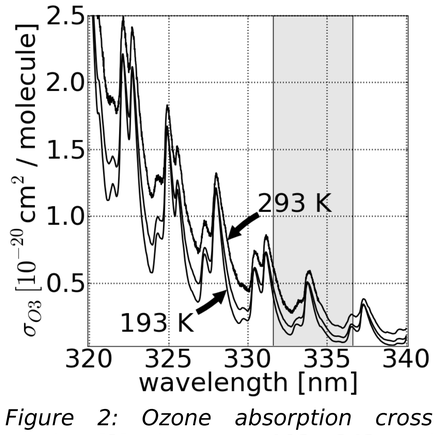


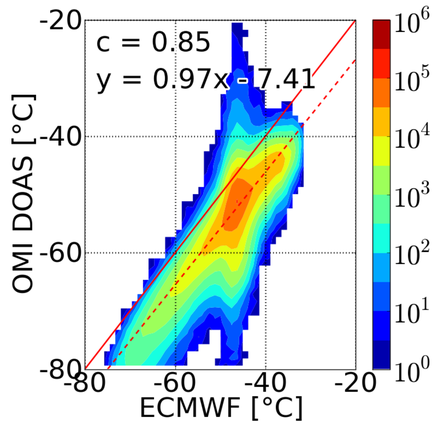
Figure 2: Ozone absorption cross sections[2] shown at 193, 243 and 293 K. The current OMI DOAS fit window is shaded.

OMI DOAS (continued)

Subsequently the slant column density is scaled to a vertical column with the air mass factor. The air mass factor is calculated with a radiative transfer model with ozone and temperature profiles from the TOMS V8 climatology. In the last step a correction is applied for clouds. Inelastic rotational Raman scattering is taken into accounted by fitting a ring spectrum (not in Eq. 1).

Validation of the fitted temperature

For a reference temperature a medium range weather forecasting (ECMWF) model is used. The temperature profile is weighted with the OMI ozone profile. See Fig. 3 for the comparison. The OMDOAO3 fitted temperature is 5.82±0.04 K too low. This is consistent for different seasons and regions. This difference can be reproduced with simulated spectra.



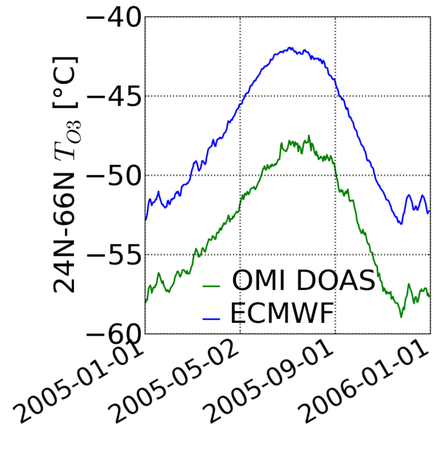


Figure 3: (upper) Scatter density plot of the OMI DOAS fitted temperature against the reference temperature. (lower) NH midlatitude temperature evolution. Data from 2005.

Temperature sensitivity

The temperature sensitivity is a concept to assess whether ozone observations depend on temperature. It is defined as the relative error in the ozone observation for a change in the ozone temperature. A temperature sensitivity of 0.01 %/K is sufficient to obtain ozone trends with 1% accuracy. This holds for climate change, volcanic eruptions, spring ozone depletion and the solar cycle. E.g. for climate change the simultaneous change of ozone (-3.5 %) and of stratospheric temperature change (-1.5 K) results in 2.3 %/K. Hence that an error of 0.01 %/K will have a negligible impact on the ozone trend (<1%). When an analytic relation is used to obtain the ozone column, the temperature sensitivity can be derived directly from the ozone absorption cross sections. See Tbl. 1.

	Temp. sens. [% / K]
Dobson (AD-DSQP)	0.125 ± 0.021
Brewer (DS)	0.014 ± 0.003
OMI TOMS	0.175 ± 0.025

Table 1: Temperature sensitivities derived from the new ozone absorption cross sections[2].

In Tbl. 1 we see that the Brewer observations have a very low temperature sensitivity. This is also found in a study by Kerr. based on observations in Toronto.[1] Therefore the Brewer observations are used as a reference ozone column amount. Consequently for OMI DOAS a temperature sensitivity of 0.028 ± 0.034 %/K is found. See Fig. 4.

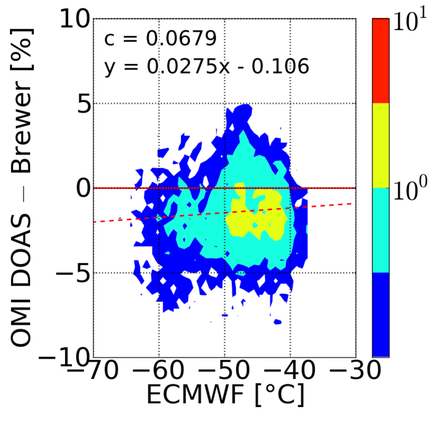


Figure 4: Scatter density plot of relative ozone column difference (OMI DOAS − Brewer) plotted against the reference temperature. Data from 2005.

DOAS improvements

New laboratory ozone absorption cross sections from Serdyuchenko[2] are available. See Fig. 2 and 5. These cross sections are measured at 11 temperatures against 5/6 of others. A 2nd degree polynomial for the temperature dependence can be used in the fit. Also a simple function with two parameters can be used to describe the wavelength-dependent air mass factor.

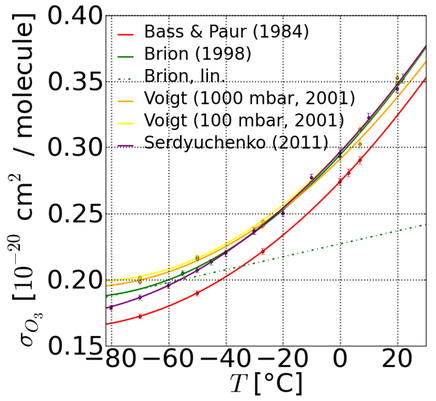


Figure 5: Temperature dependency of ozone absorption cross sections at 334.6 nm.

The optimal settings for the improvements are under investigation. See fig. 6 for a typical outcome.

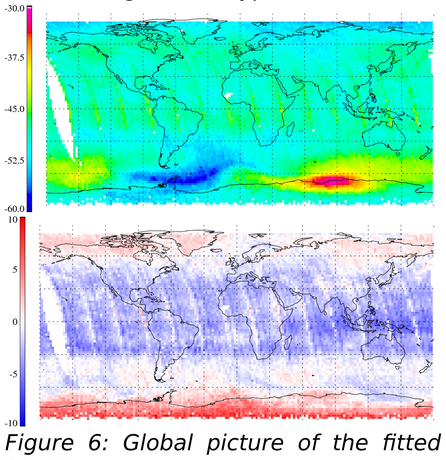


Figure 6: Global picture of the fitted DOAS ozone temperature with improvements on 2005-10-01 (upper) and difference with ECMWF (lower).

Conclusion

DOAS improvements can reduce the temperature sensitivity and enhance noise reduction.

References

[1] Kerr, J. B., New methodology for deriving total ozone and other atmospheric variables from Brewer spectrophotometer direct sun spectra, J. Geophys. Res., 2002.
[2] Serdyuchenko et al., New broadband high-resolution ozone absorption cross sections, 2011.

*albert.oude.nijhuis@knmi.nl